Data acquisition, processing and streaming for ITER Diagnostics

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Introduction

- In order to control and evaluate the plasmas produced in magnetic fusion devices it is necessary to measure the value of the key plasma parameters (density, temperature, impurities, internal magnetic fields etc.) using specially developed measurement systems termed **'Diagnostic Systems'**
- Diagnostics **measurement systems have stringent requirements in terms of high performance data acquisition, data processing and real-time data streaming** from distributed sources to the plasma control system as well as large amounts of raw data streaming to scientific archiving. There are about 50 different parameters to be measured [1])
- The technologies used range from magnetics, microwave and optical imaging systems, spectroscopy, neutron and gamma dosimetry, fusion product analyzers etc.
- The plant I&C systems must support the operational needs for : Machine Protection, Plasma Operation and Physics Exploitation

Requirements for High Performance Scientific Computing

- The computational needs of some diagnostics can reach 1 Teraflop/s depending on the selected algorithms and the required accuracy (number of data points processed).
- Scientific archiving needs will be of the order of 2 GB/s continuous (10 GB/s on demand for 3 seconds) for first plasma and 50 GB/s continuous (300 GB/s on demand) for full physics exploitation. (Refer TABLE-I.)

TABLE-I: DATA MANAGEMENT REQUIREMENTS

Diagnostics Type	Data Acquisition ADC / Camera	Data Rate for Archiving	Signal Processing complexity/resource	Algorithms
Magnetics	(0.1 – 1) MS/s	Moderate	Moderate, FPGA, CPU	Integrators, Magnetic reconstruction
Neutronics	100 Ms/s	Medium	Medium, distributed, FPGA, CPU	Pulse analysis
Optical	1 GS/s	High (peak)	Medium, FPGA, CPU	Pulse analysis
Optical Spectrometers	1 Mpixel (50 Hz)	High	Medium, FPGA, CPU	Spectral analysis
Microwave systems	1 GS/s	High (peak)	High, FPGA, CPU, GPU	Complex filtering, Bottollier-Curtet
Imaging systems	1 Mpixel (1 kHz)	High	High, FPGA, CPU, GPU	compression, reflection removal, event detection

Data Acquisition Needs for Diagnostics

- **Sampling rates** : 1,10,100, and 1000 MS/s (commercial availability of 10 GS/s (10-bit) expected in near future)
- **Bit resolution** : 16, 14, and 12
- CameraLink or GbE will be required for optical and fusion product (spectrometers) diagnostics.
- Detailed information in Figure 1

Algorithms and Real-Time Data Processing Needs

- In the case of high data rates (ADC sampling rate 100-1000 MS/s or cameras) it is desirable to implement the real-time algorithms in the FPGA which controls also the data acquisition. (Refer TABLE-III)
- **High Data Rates** e.g.: Pulse analysis, Phase reconstruction, Filtering in frequency domain, Integral transformation, Data compression, Geometry mapping, Event detection.
- **Real Time Data Processing** e.g.: Filtering, Scaling, Decimation, Fast-Fourier transform, Cross- and auto-correlation, Calibration
- **High Data Rates Systems e.g. :** Dosimetry, Microwave reflectometry, Imaging, Optical systems

Data Streaming to Archiving

The estimate (TABLE-II)depends on the demand of raw data to be archived, the possibilities of data compression (especially important for imaging diagnostics and spectroscopy) and the duty cycle of diagnostics with very high sample rates

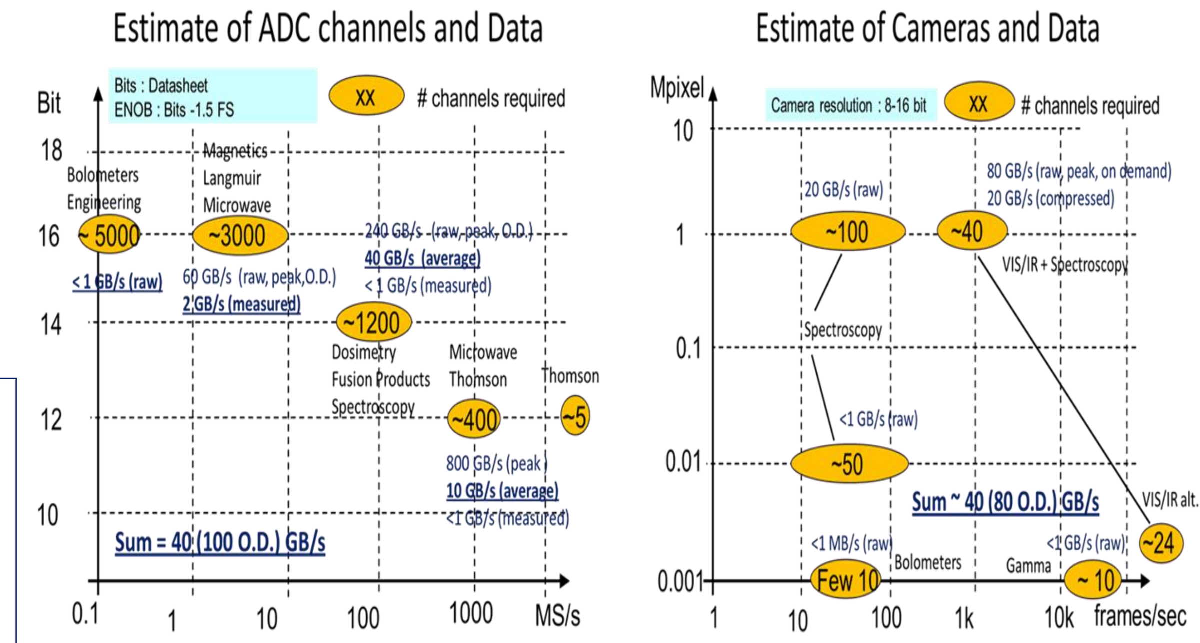
TABLE-II: REQUIREMENTS FOR DATA ARCHIVING

Streaming mode Scenario->	First Plasma	Physics Exploitation
Continuous streaming (plasma pulse)	2 GB/sec	50 GB/sec
On demand streaming (3 seconds)	10 GB/sec	300 GB/sec

Assumptions:

- First Plasma data are dominated by 4 cameras and raw data from ~2000 channels of raw data from magnetics
- Data from VIS/IR cameras can be compressed without loss / 5 [not for 1st plasma]
- Raw data from cameras from imaging spectroscopy is reduced by factor of ~10
- Raw data from fast sampling ADCs (>100 MS/s) is available only on demand for limited time
- Total data from on demand archiving does not exceed data from continuous archiving
- Data rate between pulses is much smaller (/100) than during pulse
- Most data comes from few sources (80/20 rule)

Figure 1 : PARAMETERS OF DATA SOURCES AND DATA RATES FOR ARCHIVING



Criteria for estimate of the Data Rates for Archiving :

- Number of signals and variables
- Measurement update rate and signal sampling rate
- Need for archiving of raw data, Data rates dominated by a few diagnostics
- Identified dominating data sources and estimated remaining sources

TABLE-III: ESTIMATION OF COMPUTATIONAL NEEDS FOR VIS/IR IMAGE PROCESSING TASKS

Algorithm	Function	Complexity	Time Constraint
Image compression	Data reduction	~1Gflop	<1ms
Maxima extraction	Machine Protection	1 Mflop	< 1ms
Hot spot detection	Plasma Control	~ 1Gflop	< 100 ms
Particle trajectory reconstruction	Physics Studies	~100 Tflop	>1h

Design

- The ITER I&C standards : Plant Control Design Handbook (PCDH) [2] and Computational resources including FPGAs, GPUs and multi-core CPUs.[3]
- Figure – 2 provides overall ITER I&C Architecture ; Figure - 3 explains ITER solution for Real Time Data Processing needs and Data Streaming to Archiving requirements.
- Figure - 4 provides further detail solution for Data Streaming to Archiving Needs.

CONCLUSIONS

- ITER CODAC has identified **commercially available standard fast controllers** with different performance grades which fulfil these needs.
- Currently several representative diagnostics use cases are implemented to verify the choices.

ITER Instrumentation and Control Design

Figure – 2: I&C ARCHITECTURE

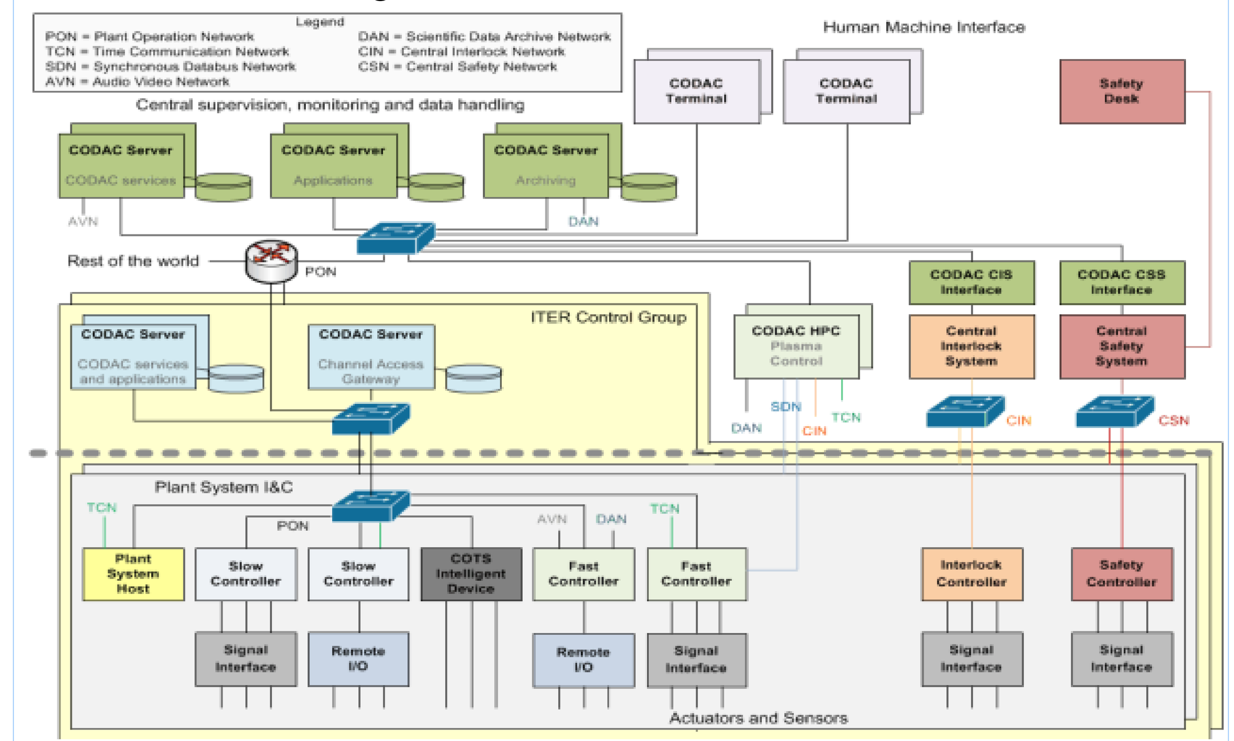


Figure – 3: FAST CONTROLLER FORM FACTOR

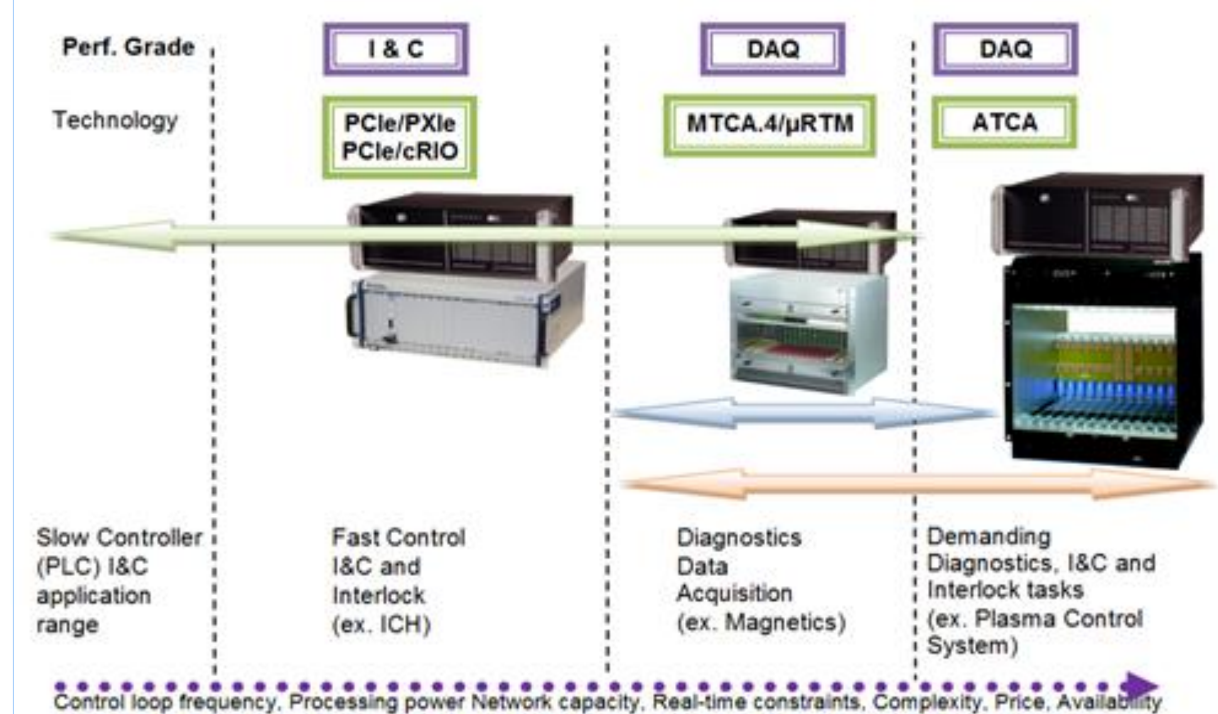
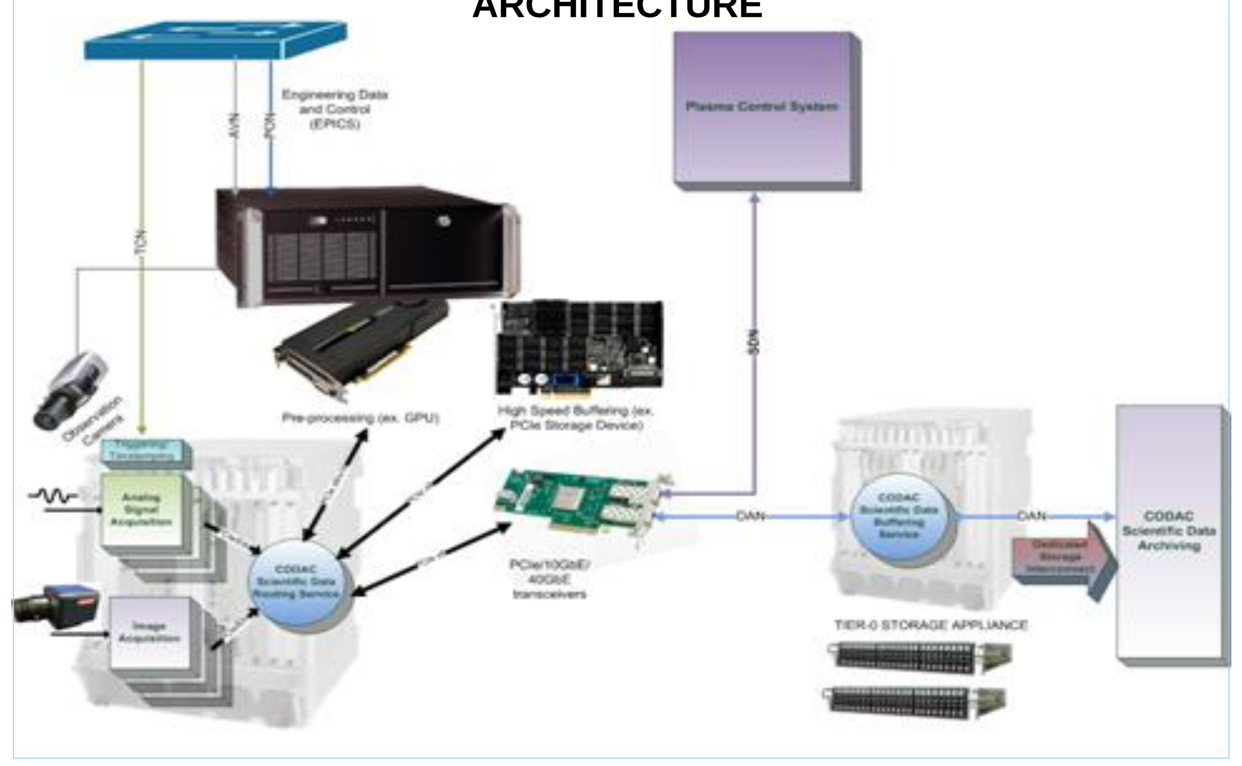


Figure-4: HIGH PERFORMANCE SCIENTIFIC COMPUTING ARCHITECTURE



REFERENCES

[1] Costley, A., IT/P6-21, Measurement Requirements and the Diagnostic System on ITER, IAEA 2008.
[2] CODAC Plant Control Design Handbook, http://www.iter.org/org/team/chd/cid/codac/plantcontrolhandbook
[3] JY. Journeaux, Instrumentation and control standardization in the ITER project, SOFT 2010

Legends

Requirements

Design

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